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CIVIL ENGINEERS



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BOSTON SOCIETY OF CIVIL ENGINEERS
FOUNDED 1848

PROCEEDINGS

SIXTY-EIGHTH ANNUAL MEETING.

THE annual meeting of the Boston Society of Civil Engineers will be held at the Boston City Club, Ashburton Place, Boston, on Wednesday, March 15, 1916.

As previously announced, the annual meeting this year will consist of three principal features: a business meeting at noon, the annual dinner in the afternoon and the smoker in the evening.

PROGRAM.

Business Meeting. — The annual meeting required by the Constitution will be called to order at 12 o'clock M. in the Assembly Room on the third floor of the Club House.

Business. — Announcement of the election of new members.

To receive the annual reports of the Board of Government, of the Treasurer and of the Secretary.

To receive the annual reports of the several special committees.

To reappoint the several special committees.

Announcement of the result of letter-ballot for officers for the ensuing year.

Presentation of the Desmond FitzGerald Medal.

Address of the retiring President.

Annual Dinner. — The thirty-fourth annual dinner will be served at half past one o'clock P.M., in the main banquet hall or auditorium on the fourth floor of the Club House.

At three o'clock Dr. Charles H. Tyndall, of Mount Vernon, N. Y., will deliver a lecture on "The Wonders of Ether Waves" and "Radium and Its Mysteries."

Smoker.—The usual informal smoker will be held in the evening in the main banquet hall, beginning at 6.30 o'clock.

S. E. TINKHAM, *Secretary*.

PAPERS IN THIS NUMBER.

"Power Estimates from Stream Flow and Rainfall Data,"
Dana M. Wood.

"Cleaning Lock Gate Trackways at Charles River Dam,"
Edward C. Sherman.

"Monkey Cart," E. F. Rockwood.

CURRENT DISCUSSION.

Paper.	Author.	Published.	Discussion Closes.
"Sand and Oil Roads and Sur- faces."	W. R. Farrington.	Feb.	April 10.

Reprints from this publication, which is copyrighted, may be made provided full credit is given to the author and the Society.

Contributors are hereby notified that proof will not be submitted to them for examination unless requested before the 10th of the month preceding the month of publication.

MINUTES OF MEETINGS.

BOSTON, MASS., February 16, 1916. — A regular meeting of the Boston Society of Civil Engineers was held this evening at Chipman Hall, Tremont Temple, and was called to order at 7.50 o'clock by the President, Charles R. Gow. There were 106 members and visitors present, including many members of the Boston Section of the American Institute of Electrical Engineers and of the American Society of Mechanical Engineers, who had been invited to join in the meeting.

By vote, the reading of the record of the last meeting was

dispensed with and it was approved as printed in the February JOURNAL.

The Secretary reported for the Board of Government that it had elected to membership in the grades named:

Members — Henry Lovell Crocker, Thomas C. Davis, Forrest Joseph Maynard and Robert Emerson Parker.

Juniors — John Hancock Babbitt, Albert Emanuel Kleinert, Jr., and William Henry Smith.

The Secretary announced the death of John H. Gerrish, an Associate of the Society, who died February 7, 1916. By vote, the President was requested to appoint a committee to prepare a memoir.

The Secretary stated that the date for holding the regular meeting in April would fall this year on the nineteenth of that month. By vote, the day on which the April meeting should be held was left with the Board of Government.

Mr. Edward C. Sherman read the paper of the evening entitled, "The Spillways of the Panama Canal." The paper was illustrated with lantern slides.

A short discussion followed, in which Messrs. L. K. Rourke, H. A. Miller and others took part.

Adjourned.

S. E. TINKHAM, *Secretary*.

BOSTON, MASS., January 5, 1916. — A regular meeting of the Sanitary Section of the Boston Society of Civil Engineers was held this evening in Gilbert Hall, Tremont Temple.

A cafeteria supper was served at six o'clock, to 80 members and guests.

The meeting was called to order by the chairman, Stephen DeM. Gage, at 7.30 o'clock.

The speaker of the evening was Major James F. Hall, Medical Corps, U.S.A., and Inspector-Instructor, Sanitary Troops of New England Militia, who gave an illustrated talk on sanitary work in the United States Army.

There were 122 present at the meeting. Adjourned at 9.30 P.M.

JOHN P. WENTWORTH, *Clerk pro tem*.

BOSTON, MASS., January 10, 1916. — A special meeting of the Sanitary Section of the Boston Society of Civil Engineers was held this evening at Myers Hall, Tremont Temple. Chairman Stephen DeM. Gage called the meeting to order at 8.00 o'clock P.M. and introduced the speaker of the evening, Dr. Edward Bartow, director State Water Survey of Illinois. Dr. Bartow gave a very interesting talk, illustrated by lantern slides, on "Activated Sludge."

The subject was discussed by Messrs. H. W. Clark, R. S. Weston, J. H. Gregory, A. L. Fales and H. P. Eddy.

The attendance was 65. Meeting adjourned at 10.15 P.M.

JOHN P. WENTWORTH, *Clerk pro tem.*

BOSTON, MASS., February 2, 1916. — A meeting of the Sanitary Section, Boston Society of Civil Engineers, was held this evening in Gilbert Hall, Tremont Temple, at 7.30 o'clock.

A cafeteria supper was served at 6.15 o'clock, to 32 members and guests.

The chairman appointed the following members to serve as a Nominating Committee to report nominations for officers at the annual meeting: Messrs. Almon L. Fales, George C. Whipple and Edward Wright, Jr.

The speaker of the evening was Mr. W. J. Sherman, consulting engineer, of Toledo, Ohio. "The Reconstruction of the Cambridge, Ohio, Water Works" was described by Mr. Sherman in a most interesting manner. Lantern slides were used to show details of the construction.

A rising vote of thanks was tendered Mr. Sherman for his courtesy in coming to Boston to address the Section.

There were 38 present, a very small attendance, due to the severity of the snowstorm, which prevented out-of-town members from attending.

Meeting adjourned at 9.05 o'clock.

FRANK A. MARSTON, *Clerk.*

APPLICATIONS FOR MEMBERSHIP.

[March 2, 1916.]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of twenty (20) days from the date given.

APPLETON, THOMAS ALLEN, Beverly, Mass. (Age 40, b. Beverly, Mass.) Educated in public schools and by private tutor. From Nov., 1892, to March, 1905, with B. & M. R. R., engineering department; from April to Oct., 1906, with N. Y. C. & H. R. R. R.; from Feb., 1906, to date, in private practice in Salem, Mass.; has been town engineer of Marblehead, and was town engineer of Danvers for four years; member of American Society of Civil Engineers. Refers to R. C. Allen, C. A. Fritz, T. P. Perkins, G. F. Temple and H. L. Whitney.

CHASE, GUY HERBERT, Fitchburg, Mass. (Age 47, b. Lowell, Mass.) Educated in public schools. Experience includes five years in engineering offices in Lowell and Boston, Mass.; nine years with N. Y. C. R. R., W. S. R. R. and R. W. & O. R. R.; five years with Massachusetts Harbor & Land Comm. and Wachusett Met. State Res. Comm.; and eight years in private practice, firm of Parker, Bateman & Chase, of which firm he is still a member; is now commissioner of streets and engineering in Fitchburg. Refers to F. W. Bateman, H. P. Eddy, J. D. Savage and C. W. Sherman.

ELLSWORTH, SAMUEL MORRISON, Braintree, Mass. (Age 21, b. Braintree, Mass.) Student at Mass. Inst. of Technology, class of 1916, sanitary engineering course. Refers to C. F. Allen, G. L. Hosmer, J. W. Howard, L. J. Johnson and A. G. Robbins.

GULESIAN, SELDEN JOHN, Revere, Mass. (Age 28, b. Marash, Turkey.)

Graduate of Mechanic Arts High School, Boston, 1907; student at Lowell Inst., winters of 1907-1909, mechanical engineering course; in 1912, completed course in steel and concrete design at Franklin Union. From 1907 to 1908, tracer on drawings with Ambursen Hydraulic Construction Co.; during summer of 1908, with Whitman & Howard Co., civil engineers; from 1909 to 1913, with H. P. Converse & Co., engineers and contractors, first as clerk, later as draftsman, estimator and designer; during 1913, held temporary positions as follows: with N. E. Gas & Coke Co., as assistant to Mr. James Taber, civil engineer for the company; as structural steel detailer with Whidden, Beckman Co., engineers and contractors, Boston; and with L. M. Ham & Co., iron and steel workers, as detailer, assistant estimator and outside inspector; in spring of 1914, established National Iron Works, Boston, of which he is owner, manager, estimator and draftsman. Refers to E. P. Bliss, H. N. Cheney, Channing Howard, W. S. Johnson and D. S. Reynolds.

LOTHROP, ERNEST ELWELL, Fitchburg, Mass. (Age 35, b. Cohasset, Mass.) From April, 1901, to 1905, with Whitman & Howard Co., Boston; from 1905 to 1906, with French & Bryant, Brookline; from April, 1906, to May, 1910, with Charles River Basin Comm., first as rodman, finally as assistant engineer; during 1910, in charge of construction of small reservoir at New Britain, Conn.; from April, 1911, to 1915, with Sewage Disposal Commission of Fitchburg, and in 1913 and 1914 had full charge of new disposal plant; during 1915, city engineer of Fitchburg, and is now principal assistant engineer to commissioner of streets and engineering of that city. Refers to W. N. Charles, H. P. Eddy, J. N. Ferguson, J. L. Howard, F. A. Marston, H. A. Miller and C. W. Sherman.

SCULLY, JOHN T., Brighton, Mass. (Age 37, b. Cambridge, Mass.) Student for three years at Mass. Inst. of Technology, civil engineering course, class of 1901. Since 1901, superintendent, estimator and president of John T. Scully Foundation Co., Cambridge; is also president of Wellesley Gravel Co. Refers to J. E. Carty, C. H. Gannett, C. R. Gow and J. F. Monaghan.

LIST OF MEMBERS.

ADDITIONS.

BABBITT, JOHN H.	20 Warland St., Cambridge, Mass.
DAVIS, THOMAS C.	15 Oak Terrace, Newton Highlands, Mass.
HUNTER, ROBERT C.	1020 Fellsway, Malden, Mass.
KLEINERT, ALBERT E., Jr.	108 St. James Ave., Boston, Mass.
MAYNARD, FORREST J.	23 Irving St., Watertown, Mass.
McSWEENEY, THOMAS F.	Framingham, Mass.
PARKER, CHARLES F.	Woonsocket, R. I.
SMITH, WILLIAM H.	65 Dartmouth Ave., East Dedham, Mass.
SNOW, LESLIE W.	Care Ames Plow Co., Framingham, Mass.
WAITE, EDWARD B.	Millbury, Mass.

PROCEEDINGS.

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CHANGES OF ADDRESS.

ALLARDICE, JAMES P.	91 Barnaby St., Fall River, Mass.
ALLBRIGHT, EDWIN F.	584 Columbia Road, Dorchester, Mass.
ALLEN, C. FRANK.	88 Montview St., West Roxbury, Mass.
ALLEN, LESLIE H.	27 School St., Boston, Mass.
BAKER, LLOYD E.	City Engineer's Office, Providence, R. I.
BALCH, WM. H.	46 Green St., Hudson, Mass.
BARNES, ARTHUR B.	664 Pearce St., Fall River, Mass.
CASHMAN, JOHN M.	137 Irving St., Watertown, Mass.
CLUKAS, GEORGE M.	161 Devonshire St., Boston, Mass.
CURTIS, ALLEN	8 Liberty St., Gloucester, Mass.
DEAN, ARTHUR W.	Room 212, State House, Boston, Mass.
DOLLIVER, HENRY F.	808 Main St., Westbrook, Me.
DRAKE, HENRY P.	Box 185, Harrisburg, Pa.
ELLIS, JOHN W.	Turk's Head Bldg., Providence, and Woonsocket, R. I.
ELLIS, LESTER F.	36 Adams St., Winter Hill, Mass.
EMERSON, RALPH W.	90 North St., Pittsfield, Mass.
FIELDING, WM J., care Harbor and Land Comm.,	State House, Boston, Mass.
FORD, WALTER A.	6 Vesta Road, Dorchester Centre, Mass.
GARROD, J. ARTHUR.	35 Powder House Terrace, W. Somerville, Mass.
HALL, CHARLES L.	Care Standard Oil Co., Shanghai, China
HAMMOND, WILBERFORCE B.	79 Milk St., Boston, Mass.
HARRIS, GILBERT M.	319 Huntington Ave., Suite 4, Boston, Mass.
HAYWARD, EDWIN D.	643 East Seminary St., Greencastle, Ind.
HAZELTON, CHARLES W.	Montague City, Mass.
HERRICK, HENRY A.	Care Montana Power Co., Butte, Mont.
HOLWAY, WM. R.	Kent, R. I.
HUNTER, HARRY G.	Pike Hill Copper Mines, Corinth, Vt.
JEROME, FRANK J.	435 Palmwood Ave., Toledo, Ohio
MCCURDY, HARRY S. R.	Miami Conservancy District, Dayton, Ohio
NEGUS, ARTHUR I.	147 Milk St., Boston, Mass.
PARKER, CHARLES H.	1056 Beacon St., Brookline, Mass.
PINKHAM, MILLARD B.	55 Hanson Pl., Brooklyn, N. Y.
PREBLE, J. JARVIS	80 Howard St., Waltham, Mass.
REW, MORSE W.	Rapid Transit Comm., Cincinnati, Ohio
RICHARDSON, LYLE M.	515 Dixwell Ave., New Haven, Conn.
ROUTENBERG, HENRY W.	P. O. Box 24, Richardson Park, Del.
SARGENT, EZEKIEL C.	149 Putnam St., Quincy, Mass.
SMALL, GILBERT	Cottage St., Belmont, Mass.
SOUTHER, THEODORE W.	516 Audubon Road, Boston, Mass.
STEVENS, GEORGE M.	228 Southampton St., Boston, Mass.
STORRS, HARRY A.	Box 352, Tucson, Ariz.
TREADWELL, EDW. D.	55 Marshall Pl., Webster Groves, Mo.
WALKER, PHILLIP B.	91 Bradford St., Needham, Mass.
WHITNEY, RUSSELL H.	56 Sea St., North Weymouth, Mass.

CHANGES OF ADDRESS — CONTINUED.

WINSLOW, FREDERICK I. 66 Bloomfield St., Dorchester, Mass.

DEATH.

GERRISH, JOHN H. February 7, 1916

EMPLOYMENT BUREAU.

THE Board of Government maintains an employment bureau for the Society, to be a medium for securing positions for its members and applicants for membership, and also for furnishing employees to members and others desiring men capable of filling responsible positions.

At the Society room two lists are kept on file, one of *positions available* and the other of *men available*, giving in each case detailed information in relation thereto.

MEN AVAILABLE.

246. Age 35. High school education, supplemented by evening courses, etc. Has had five years' experience on railroad work, five years on municipal work, and six years on general engineering work, including Panama Canal, international boundary, reclamation, etc. Desires position as engineering assistant. Minimum salary desired, \$100 per month.

289. Age 29. Graduate of Middlebury College, Vt. Has had three years' experience as transitman, draftsman and levelman. Desires position as draftsman and transitman with civil engineer. Salary desired, \$12 to \$18 per week.

342. Age 28. Graduate of Dartmouth College, with degree of B.S., 1909; senior year in Thayer School of Civil Engineering. Has had about six years' experience as rodman, instrumentman, chief of party, draftsman and assistant engineer on dam construction, boundary surveys, harbor improvements and construction of sewage filtration beds. Desires position as assistant engineer or chief of party upon water supply, sewage disposal, general construction or general surveying work. Salary desired, \$125 per month.

348. Age 44. Received technical education from home study and experience in engineering offices. Has had about eight years' experience, including computations, estimates and drafting for water supply and sewerage systems; also design of reinforced concrete structures, such as pumping stations, Imhoff tanks, etc. Desires position as assistant engineer in some consulting, hydraulic, sanitary, or construction engineer's office. Salary desired, \$125 per month.

349. Age 35. Received technical education chiefly from correspondence school courses and Franklin Union; has passed the Massachusetts civil service examination for civil engineers, Grade C. Has had fifteen years' experience, including five years with private firm on general engineering and ten years on construction work, the latter consisting mainly of dam, sewer and reservoir construction; served for one year as city engineer of Massachusetts city having population of 37 000. Desires position as engineer in charge of construction. Salary desired, \$200 per month in temporary position, or \$180 per month in permanent position with chance to advance.

350. Age 24. Graduate of Harvard College, 1914, with degree of S.B. Has had about one and one-half years' experience, including one year as transitman with city engineer and five months as recorder with engineering firm. Desires position as transitman. Salary desired, \$20 per week.

LIBRARY NOTES.

BOOK REVIEWS.

Examples in Alternating Currents, Vol. 1. By F. E. AUSTIN. Hanover, N. H., 1915. Pp. 223, 76 illustrations. Price, \$2.40.

Reviewed by Thomas E. Penard.

The work is an excellent reference book for students and teachers who are interested in the theory of alternating currents. The mathematical principles are amply illustrated by carefully worked-out problems.

The work covers: Usual notation, — those portions of trigonometry which are applicable to alternating current work; brief rules for differentiation and integration with special reference to types occurring in alternating currents; an introduction to alternating currents with special reference to wave forms, average and effective values, form factors for various waves, a treatment of non-sinusoidal waves, etc.

The author continues with a clear treatment of the subject of inductance and capacity, devoting nearly one half the volume to a discussion of these essential elements, and richly illustrating the principles by carefully chosen problems. Nine pages at the end are devoted to tables of special usefulness in alternating current work.

On page 7 there is a typographical error, giving the value of a Radian as 50.295799 instead of 57.295799. In view of the general excellence of this little volume, it is to be hoped that the numerical work is otherwise free from such errors, and we are looking forward with interest to the appearance of the second volume, which is expected to be ready in the early fall of this year.

How to Make Low-Pressure Transformers. By F. E. AUSTIN. Hanover, N. H. Second edition. Price, \$0.40.

Reviewed by Thomas E. Penard.

This little volume gives working directions for making small transformers of from 100 to 400 watts capacity, for connection to 110-volt, 60-cycle circuits, such as are used for electric bells, spark coils, gas engine ignition, etc.

The treatment is simple and the working directions complete. There are several illustrations. Any one of ordinary ability following the directions can construct these small transformers.

Directions for Designing, Making and Operating High-Pressure Transformers. By F. E. AUSTIN. Price, \$0.65.

Reviewed by Thomas E. Penard.

This little volume gives directions for the design of small step-up transformers giving 20 000 volts for use in connection with wireless telegraphs, telephones, etc. Theory is introduced wherever necessary, and useful tables are included. The mathematics are simple and well within the grasp of the average student.

RECENT ADDITIONS TO THE LIBRARY.

U. S. Government Reports.

Recent Alunite Developments near Marysvale and Beaver, Utah. G. F. Loughlin.

Annual Report of Bureau of Civil Service to Governor-General of Philippine Islands for 1914.

Annual Report of Chief of Engineers of United States Army for 1915. 3 vols.

Annual Report of Director of Geological Survey for 1914-15.

Annual Report on Statistics of Railways for 1913-14.

Aztec Gold Mine, Baldy, New Mexico. Willis T. Lee.

Cassiterite in San Diego County, California. Waldemar T. Schaller.

Production of Coal in 1914. C. E. Leshner.

Copper in 1914. B. S. Butler.

Reconnaissance of Cottonwood-American Fork Mining Region, Utah. B. S. Butler and G. F. Loughlin.

Field Apparatus for Determining Ash in Coal. C. E. Leshner.

Geology and Coal Resources of Northern Teton County, Montana. Eugene Stebinger.

Notes on Fine Gold of Snake River, Idaho. J. M. Hill.

Gold, Silver, Copper, Lead and Zinc in Arizona in 1914. V. C. Heikes.

Gold, Silver, Copper, Lead and Zinc in Idaho and Washington in 1914. C. N. Gerry.

Gold, Silver, Copper, Lead and Zinc in Montana in 1914. V. C. Heikes.

Heat Transmission through Boiler Tubes. Henry Kreisinger and J. F. Barkley.

Production of Iron Ore, Pig Iron and Steel in 1914. Ernest F. Burchard.

Lead in 1914. C. E. Siebenthal.

Production of Metals and Ores in 1913 and 1914. J. P. Dunlop.

Production of Natural Gas in 1914. John D. Northrop.

Natural Gas Resources of Parts of North Texas. Eugene Wesley Shaw, George Charlton Matson and Carroll H. Wegemann.

Petroleum in 1914. John D. Northrop.

Public Interest in Mineral Resources. George Otis Smith.

Summary of Railway Returns for Fiscal Year Ending June 30, 1915.

Water-Supply Papers 351, 371, 400-A.

Origin of Zinc and Lead Deposits of Joplin Region, Missouri, Kansas and Oklahoma. C. E. Siebenthal.

County Reports.

Essex County, Mass. Engineer's Report for 1915.

Municipal Reports.

Boston, Mass. Annual Report of Public Works Department for 1914.

Boston, Mass. Annual Report of Transit Commission for 1915.

Boston, Mass. Digest of Health Laws, 1904. Gift of F. I. Winslow.

Melrose, Mass. Annual Report of Park Commissioners for 1915.

New Bedford, Mass. Annual Report of Water Board for 1915.

New York, N. Y. Contract 170, Board of Water Supply: Copper Lining in Portion of City Tunnel of Catskill Aqueduct.

New York, N. Y. Annual Report of Department of Water Supply, Gas and Electricity for 1914.

Reading, Pa. Annual Report of Bureau of Water for 1913-14.

Miscellaneous.

American Handbook for Electrical Engineers. Harold Pender.

American Wood Preservers' Association: Quantity of Wood Preservatives Consumed and Amount of Wood Treated in United States in 1914. Clark W. Gould.

Architects' and Builders' Pocket-Book. 16th ed. Frank E. Kidder.

Canada, Department of Mines: Petroleum and Natural Gas Resources of Canada. Vol. II. Frederick G. Clapp and others; Summary Report of Mines Branch for 1914.

Clean Water and How to Get It. 2d ed. Allen Hazen.

George Ward Blodgett: a Memoir. Henry Ayling Phillips. Gift of Class of 1873, Mass. Inst. of Technology.

Institution of Civil Engineers (London): Minutes of Proceedings. Vol. CC.

International Congress on Hygiene and Demography, 1912: Transactions. 9 vols. Gift of William F. Morse.

International Engineering Congress, 1915: Transactions, Mechanical Engineering.

Alexander Milburn Co.: Milburn Light.

National Board of Fire Underwriters: Regulations Recommended for Storage and Handling of Nitro-Cellulose Motion Picture Films, 1915; Regulations Recommended for Installation of Vaults, 1916.

Reinforced Concrete Construction. Vol. III. George A. Hool.

Principles of Reinforced Concrete Construction. F. E. Turneaure and E. R. Maurer.

River Discharge. John Clayton Hoyt and Nathan Clifford Grover.

Practical Methods of Sewage Disposal. Henry N. Ogden and H. Burdett Cleveland.

Steam-Boiler Economy. William Kent.

Design of Steam Boilers and Pressure Vessels. George B. Haven and George W. Swett.

Structural Engineers' Handbook. Milo S. Ketchum.

Theory of Structures. Charles M. Spofford.

Examples in Alternating Currents. Vol. I.

Directions for Designing, Making and Operating High-Pressure Transformers.

How to Make Low-Pressure Transformers.

Above three items gift of author, F. E. Austin, and are reviewed in this issue.

Water Purification Plants and Their Operation. Milton F. Stein.

LIBRARY COMMITTEE.

NEW ENGINEERING WORK.

(Under this head a brief description of new engineering work contemplated or under construction will be presented each month. Engineers and contractors are requested to send descriptions of their work to the Secretary, 715 Tremont Temple, Boston, before the first of each month.)

Commonwealth of Massachusetts.—METROPOLITAN WATER AND SEWERAGE BOARD. — *Water Works.*

Bellevue Reservoir. — The construction of the masonry tower on Bellevue Hill in West Roxbury is completed with the exception of the tiling on the roof, work on which is in progress during favorable weather.

Sudbury Power Plant. — The work of installing the hydro-electric machinery at the Sudbury Dam in Southboro is in progress.

Sewerage Works. — Work is in progress on Section 19, Malden River Siphon, under compressed air; Section 104, Wellesley extension sewer; and the Deer Island Outfall Sewer Extension.

The new work contemplated includes Sections 98 to 102 of Wellesley extension.

METROPOLITAN PARK COMMISSION. — The following work is in progress:

Charles River Reservation. — The work of building reinforced concrete bridge over the Charles River at North Beacon St., Boston and Watertown, is in progress. A. G. Tomasello, contractor.

Plans are being prepared for bridge over the Charles River at Commonwealth Ave., between Newton and Weston, and bids will be asked for the work before spring.

Work of excavating channel of Charles River from Elm St. to Bleachery Dam, Waltham, is in progress. John R. Burke, contractor.

Furnace Brook Parkway. — Work of construction of parkway extension from Quincy Shore Reservation to Hancock St. is in progress. John Cashman & Sons Co., contractor.

Work of building reinforced concrete girder bridge across Blacks Creek, for Furnace Brook Parkway Extension, is in progress. Hugh Nawn Contracting Co., contractor.

Mystic Valley Parkway. — Work of excavating the channel of Aberjona River from Boston & Maine Railroad Bridge to Waterfield St., Winchester, is in progress. Coleman Brothers, contractors.

Old Colony Parkway. — Plans are being prepared for bridge over the Neponset River, Boston and Quincy, to replace old Neponset Bridge.

DIRECTORS OF THE PORT OF BOSTON. — *Reclamation of State Flats at East Boston.* — During the latter part of November, 1915, the Directors awarded to the Bay State Dredging & Contracting Co. the first of three contracts in the reclamation of state flats adjacent to Jeffries Point, East Boston.

Substantial progress has been made under this contract, which involves the construction of a timber retaining structure 2 200 ft. in length. About 60 000 cu. yds. of filling material have been placed along the line of the structure, and a considerable amount of pile driving has been done by the William L. Miller Co.

Bids were opened by the Directors on March 6, 1916, for the excavation of 450 000 cu. yds. of material in the removal of a large shoal off the Mystic Wharf of the B. & M. R. R. Co. The removal of this shoal will greatly facilitate handling of shipping in Mystic River, and the material removed will be deposited at East Boston and there used for filling the state flats. On the same date the Directors opened bids for depositing by the hydraulic process 1 000 000 cu. yds. of material. This amount of material will fill an area of 35 acres to 16 ft. above mean low water. If contracts are awarded, it is expected that this reclamation will be accomplished during the present season.

Removal of Shoals at Weymouth Fore River. — A contract was made with the Bay State Dredging & Contracting Co. for furnishing plant to drag down shoals in Weymouth Fore River in order to facilitate the removal of the U. S. Battleship *Nevada* from the yards of the Fore River Shipbuilding Plant.

These shoals were removed to a depth of 19 ft. below low water in six working days.

Railroad Track at South Boston. — Plans are in preparation for the extension of two industrial railway tracks from the freight yard of the N. Y., N. H. & H. R. R. Co. to the lands of the Commonwealth south of Summer St.

By the installation of these tracks state lands valued at about \$1 000 000 will be made available for industrial and warehouse purposes, with rail connection to the system of the N. Y., N. H. & H. R. R. Co.

Sewer in Fargo St., South Boston. — A sewer is being installed in Fargo St. by James H. Ferguson. This sewer will extend from D St. to a connection with the sewer of the City of Boston at C St.

Street Railway Tracks to Fish Pier. — With the coöperation of the Boston Elevated Railway Co., plans and specifications are being prepared for the installation of a double-track street railway from Summer St. along the viaduct and ramp to the Fish Pier at South Boston.

Extension of Northern Ave. to Dry Dock. — The Charles R. Gow Co. has completed a series of wash borings to determine the character of foundation along the line of Northern Ave. from the Fish Pier to the Dry-Dock, and the Directors have completed plans and specifications for this extension of Northern Ave. by the construction of a timber bulkhead and the utilization of cinders, ashes and material from cellar excavations at South Boston for the filling material.

Removal of Hamburg-American Steamships. — The interned Hamburg-American steamships *Amerika* and *Cincinnati* have been removed from Commonwealth Pier 5 to new berths at East Boston. By the removal of these steamships the westerly side of the terminal is made available for the docking of freight steamships with cargo.

Dry-Dock. — At the dry-dock the Holbrook, Cabot & Rollins Corporation has continued to assemble plant and to lay standard gage railroad tracks in preparation for construction work.

A large force of men are cutting dimension stone at the quarries of the Rockport Granite Co., and considerable granite has been delivered at the site of the dry-dock.

Excavation of earth overlying the rock at the dry-dock site is being done by the large clam-shell dredge of the Morris & Cumings Dredging Co. with a 10 cu. yd. bucket. About 250 000 cu. yds. of material have been removed.

Cofferdam construction across the entrance to the dry-dock has been started at each end. This dam will be similar to that constructed by the Holbrook, Cabot & Rollins Corporation around the lock at the Charles River Dam, and consists of two lines of timber sheeting driven well into the clay bottom. These lines of sheeting are supported by the customary pile and timber supports with earth filling within to 17 ft. above low water and on either side to high water.

Boston Transit Commission.—*Dorchester Tunnel.*—Descriptions of Sections D, E, G and H were printed in the JOURNAL in October and December, 1915.

Section D includes the station under Dewey Square, to be known as South Station Under. The interior finish on the walls consists of terrazzo and mosaic tile, above which is white Portland cement plaster, which is nearing completion. Escalators of the cleat type are being installed, and shelters of polished granite and concrete are being erected over the entrances and exits of the station.

In Section E both shields are under the channel, the one for the easterly tunnel being within about 700 ft. and the one for the westerly tunnel within about 1 300 ft. of the northerly end of the section, where they will meet the completed tunnel at the easterly end of Section D under Summer St. About two thirds of the construction of Section E is done.

On Section G, construction by the tunnel method of the 3 ft. by 5 ft. and 4 ft. 9 in. by 5 ft. 6 in. intercepting sewer in Dorchester Ave. is in progress.

The construction of the pump well at B St. and the excavation for the incline and for the tunnel by open cut between West Fourth and B streets in Dorchester Ave. is in progress. Tongued and grooved sheeting is being driven.

The construction of Section H has been substantially completed with the exception of a pump well at D St. and a ventilating chamber and emergency exit near Woodward St.

The Fore River Shipbuilding Co., Quincy, Mass., has the following work in progress:

Seventeen submarines for United States Navy.

One submarine for Spanish Navy.

Three oil steamers for the Texas Co.

Four freight steamers for the Luckenbach Co., Inc.

Three molasses steamers for Cuba Distilling Co.

One oil steamer for Argentine Republic.

BOSTON SOCIETY OF CIVIL ENGINEERS
FOUNDED 1848

PAPERS AND DISCUSSIONS

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POWER ESTIMATES FROM STREAM FLOW AND
RAINFALL DATA.

BY DANA M. WOOD,* MEMBER BOSTON SOCIETY OF CIVIL ENGINEERS.

SCOPE OF NOTES.†

THE analysis of rainfall and run-off records and the making of estimates of available power and expected financial returns cover quite different lines of investigation, but they are so closely related that they must be considered together. The former considers the raw material and the latter the manufactured product.

In these notes we have not concerned ourselves with the intermediate steps, the tools and process of manufacture, except in knowing to what extent they affect the amount and cost of the output. In other words, we must know the amount of shrinkage which takes place in changing the raw material to the finished product, and its resultant effect upon cost. The determination of the amount of shrinkage which may be economically allowed is another problem, — that of design, — and in this study we are interested only in knowing whether this amount has been estimated to be 30 or 60 per cent. with a given development scheme.

NOTE. This paper will not be presented at a meeting of the Society, but discussion is invited, to be received by Edward C. Sherman, Editor, 6 Beacon Street, Boston, before May 10, 1916, for publication in a subsequent number of the JOURNAL.

* With Stone & Webster Engineering Corp., Boston.

† An index of this paper is printed on pp. 119-120.

Assuming that the development scheme of an existing or contemplated plant has been planned along the most economical lines as regards first cost, a complete investigation of the power available at any water-power site resolves itself into the following general cases:

(A) A compilation of all available rainfall and run-off records applicable to the case under consideration.

(B) A study of their reliability.

(C) A determination of the most probable run-off for typical years at the given site.

(D) A brief study of the available market, primarily to determine probable load factors.

(E) Modification of flow estimates on account of available storage and pondage.

(F) Estimates of the power available.

(G) Corresponding financial returns for various operating conditions.

The ultimate purpose of any analysis of rainfall and run-off data is to determine the quantity and distribution of the stream flow available, which, in turn, offers the basis for estimates of

(1) The economical plant capacity.

(2) The maximum uniform load in kilowatts (or horsepower) which can be depended upon at all times in all years, and known as primary power.

(3) The length of time that other loads will be available, these loads varying between this primary power and the plant capacity, and being classed as "secondary power," using the latter term in its broader sense.

(4) The expected energy output in kilowatt (or horsepower) hours corresponding to these primary and secondary loads.

(5) The expected financial returns.

In case some form of relay power is available, other more or less complex estimates are required, such as that of the amount of auxiliary power needed to increase the water primary power to required or desirable higher amounts, times during typical years when it will be required to supplement the water, etc.

It is appreciated that no one simple method of analysis

will give all of the desirable information in any given case, but it has seemed worth while to evolve a method that with one set of comparatively simple computations will give most of it, leaving only a few items for special investigation.

In choosing the methods to be used, it is important to remember that in most cases predictions or estimates are for the future and that they are based upon past records. Owing to unforeseen changes in regard to the load conditions, power rates, etc., departures from the expected occasionally result. The purpose of any careful estimate, however, is fulfilled generally if the order of magnitude of the development, both physical and financial, is indicated.

It is the purpose in these notes to mention briefly a number of methods used by engineers in attacking certain features of the general problem and to introduce for purposes of discussion some modifications of these methods.

A. — RAINFALL AND RUN-OFF BASE DATA.

RAINFALL DATA.

Practically all important precipitation records are obtained under the direction of the U. S. Weather Bureau, which has divided the country into districts and sections, according to geographical location. The statistics for the more important meteorological stations can be found in the "Monthly Weather Review." Statistics for many of the less important stations can be found only in the monthly summary reports issued by the various districts. A publication entitled, "The Climatological Data for the United States, by Sections," contains complete records at many stations up to 1908 and 1909. Complete bound records for all stations can usually be found in the larger district offices of the U. S. Weather Bureau.

Important additional data can often be found in publications by special commissions or bureaus, such as those issued by the New York State Water Supply Commission, Maine Water Storage Commission and others.

In the presentation of rainfall tables, it is the universal custom to obtain the average annual rainfall by totaling the

average amounts for each month of record. It is desired to call attention to the fact that in many investigations this method may be misleading, as it gives too high results. A few months of excessive rainfall, for instance, will materially increase the monthly average, since their total will equal that of many very low months. It is suggested that a better method in some cases might be to tabulate the number of occurrences of various amounts of rainfall and to then obtain a mean for each month, adding these together as before, to obtain the yearly average. This suggestion is of course quite revolutionary.

RUN-OFF DATA.

Run-off records at many localities can be found in the following publications, which are arranged in the order of their usefulness and dependability:

1. Water supply papers, U. S. Geological Survey, Water Resources Branch.
2. Reports by special state commissions and boards.
3. Flood elevations on many navigable rivers are published by the U. S. Weather Bureau.
4. Private records (not published).

Full information regarding standard field and office methods used in obtaining and compiling run-off data can be found in the following:

1. "River Discharge," by J. C. Hoyt and N. C. Grover; John Wiley & Sons.
2. Numerous publications of the U. S. Geological Survey, Water Resources Branch.

It is assumed in that which follows that all available records applying to a given case have been collected and compiled in the following standard form for each station:

1. General description of the river basin.
2. Description of the gaging station.
3. List of discharge measurements.
4. Station rating curve and table.
5. Tables of mean daily gage heights.
6. Tables of daily discharge estimates.
7. Monthly summary tables.

B. — RELIABILITY OF RECORDS.

RAINFALL RECORDS.

Practically all government records are taken by coöperative observers, who usually receive no recompense for their services. Generally, observations are made accurately and honestly, but at times they are not. The government bureau, owing to lack of appropriations, can exercise very little close supervision in the form of frequent personal visits to the observer, and there is no way of determining the reliability of the records other than through a personal knowledge of the conditions at the station under consideration.

In some cases the stations are well located, but in others the convenience of the observer has been consulted, to the detriment of the accuracy of the records.

Then, again, the standardized methods of to-day may in many cases be materially different and better than in the earlier records. This is of great importance in drawing conclusions from very long-term records.

As a check on the reliability of long-term records in New England, the following relations may be useful. Similar relations can profitably be determined for other sections of the country:

Rainfall in very driest year	= 0.6 to 0.7 of average for long series of years.
Rainfall in ordinary dry year	= 0.8 of average for long series of years.
Rainfall in wettest year	= 1.3 to 1.5 of average for long series of years.
Rainfall in very driest year	= 0.4 to 0.5 of that in very wettest year.

RUN-OFF RECORDS.

To determine the reliability of run-off records, it is customary to make comparisons between stations.

The commonly used unit of discharge is the "second-foot," an abbreviation for cubic feet per second, and equivalent to that quantity of water flowing in a stream one foot wide, uniformly one foot deep, at a velocity of one foot per second.

Units of Comparison.

Comparisons of *daily* run-off records show very considerable differences, even for neighboring stations, because of variations in precipitation in the respective watersheds, of control by existing power plants, and other reasons. It is preferable, therefore, to compare the average run-off for longer periods of time, and a month is the period frequently chosen for comparisons.

To eliminate the effect of the size of the watershed areas, it is customary to compare *unit* rather than total rates of flow, and the common unit is the "second-foot per square mile of watershed." In special cases the unit rate may be based upon the net land area, deducting that of the existing water surface areas comprised in the lakes and ponds in the basin.

The U. S. Geological Survey has recently inaugurated the practice of showing comparisons of the monthly average rates of flow in second-feet. Where this is done, the ratios of the drainage areas involved should first be determined as a guide to the normal ratios of discharge. All drainage area ratios should be less than unity, — that is, in their determination, the area of the upstream station, or the smaller watershed, should be used as the numerator.

Comparison of Monthly Records.

Natural or artificial causes entirely apart from errors in collecting and compiling stream flow data may make the ratio of monthly mean discharge *in second-feet* at two stations in the same basin depart widely from the ratio of drainage areas. The amount of probable departure depends primarily upon the magnitude of the ratio of the drainage areas. If the drainage area ratio is very small, little significance can be attached to a very wide departure in the monthly mean discharge ratios from the drainage area ratio. The important fact is that all second-foot discharge ratios between two stations should be *less than unity*, otherwise the records are in error.

The following statements apply only to dependent streams, that is, streams whose discharge in the numerator of the ratio is also included in the denominator.

1. In general, unless the discharge is controlled by artificial storage, the ratio of mean monthly discharge in second-feet should be lower than the drainage area ratio during the period when the streams are frozen; higher during the spring run-off; lower during the late summer and fall; higher during periods of high water and lower during periods of low water.

2. Ratios of unit run-off per square mile should be less than unity when the streams are frozen and during periods of low water, and greater than unity during periods of high water.

3. At certain times of the year there may be considerable departure from the above general statements, on account of the unequal distribution of precipitation and run-off. These inequalities are more evenly balanced over large areas than over small ones. For long periods, such as a year or more, the second-foot discharge ratio as a rule should be very nearly the same as the drainage area ratio, although there are many notable exceptions to this rule, particularly for drainage area ratios less than about 0.60.

Natural variations in conditions affecting run-off in adjacent independent areas are so great as easily to render unadjusted ratio comparisons of discharge of little value. When, however, the records at each station are reliable, it is often possible to establish some definite similarity or relation in run-off, as will be shown later.

Application of General Principles as Broad Checks.

In investigating apparent discrepancies in the monthly mean discharge ratios, consideration should be given to the relative amount of precipitation in the partial areas and also to the natural and artificial conditions which may possibly affect the discharge.

Ice and log jams below stations may, for instance, result in an estimate of the discharge which is altogether too high, owing to the resultant back-water conditions.

The records of discharge obtained at dams are usually not as satisfactory as records obtained at current meter stations, owing principally to the involved character of the determination of the discharge at any dam, which requires many assumptions and the use of hypothetical formulæ.

The ratio of the maximum to the minimum daily or momentary discharge will decrease as the size of the drainage area increases.

The larger the drainage area on a given river, the lower will be the unit run-off (in second-feet per square mile) for a short period of time. The reasons for this are that —

(1) Rainfall is unevenly distributed over a given basin, the total effect being less than if it had occurred uniformly.

(2) Rainfall usually (not always) increases with altitude.

(3) Heavy local rains near the lower station usually have a less total effect than if occurring at the upper because of the increase in ground storage capacity at the lower, due to the flattening out of the slopes, and to the change in character of the soil.

If two stations are within a few miles of one another, the second-foot coefficient of relation may vary from unity at low flows to the drainage area ratio at high rates of discharge.

In general, the yield of a large watershed is more steady and suffers less in drought than a small watershed.

C. — DETERMINATION OF MOST PROBABLE RUN-OFF FOR TYPICAL YEARS AT GIVEN SITE.

The selection of the method to use in determining the probable run-off for various periods for typical years at a given site will depend largely upon the character of the available records, which will usually come under one of the following general classifications:

1. Ample long-term run-off records at the site under consideration.
2. Short-term run-off records at the given site and long-term records at other points in the same or neighboring watersheds of similar characteristics.
3. No run-off records at the particular site, but numerous records at stations in the same or neighboring watersheds of similar characteristics.
4. No run-off, but ample rainfall records within reasonable distance.

In the second and third cases the records at distant sites are reduced to estimates of run-off at the given site. This requires comparisons between the various records, and the determination of average relations. It is obvious that in such cases estimates for the locality under consideration are more or less approximate.

In the fourth case, dependence must be placed entirely upon rainfall records. Many attempts have been made in the past to apply percentage relations of run-off to rainfall as determined by actual records in more or less distant watersheds of similar characteristics. Recently, more precise methods have been suggested.

C-I. — AMPLE RUN-OFF RECORDS AT GIVEN SITE.

Methods of Obtaining an Average Year's Run-off.

1. A little-used method of determining the run-off during an average year is to prepare a table with rates of flow, either in second-feet or second-feet per square mile, arranged in order of years and calendar months, and to compute the average discharge for each calendar month.

This method invariably gives too high results. To show an extreme case of this, assume that in a period of one year, the rates of run-off for three months were very high, while for the remaining nine months they were very low. The arithmetical average in this case would be very much higher than the true mean, which should take into account the number of occurrences of different rates of flow. It is the number of occurrences rather than the average rate of flow which the investigator desires to obtain.

2. A second method very commonly used is to prepare a table with the monthly flow records arranged in order of years, but with the months arranged in order of dryness. The "driest months" are averaged, then the "second driest months," etc., and a computed average year thus obtained.

While more conservative than the first method, this also gives too high results.

3. A still more conservative method is to arrange the flow

records by months in order of dryness, regardless of the year in which they occurred, and to then compute the run-off for an average year in a manner similar to the previous two cases. For example, if a fifteen-year record is being used, the fifteen driest months found in the entire period are first averaged, then the fifteen second driest, etc.

This, or as modified below in No. 7, is probably the most satisfactory method to use when only monthly flow records are available and more refinement is not desirable.

4. The next possible refinement in method which some engineers have resorted to is similar to the three preceding, but consists in analyzing average *weekly* instead of monthly flow records.

5. We now come to the method of analyzing run-off records most commonly used to-day. It is really an adaptation of the second method described above, and probably has the greatest range of usefulness and interpretation of any of the methods.

The discharges or corresponding gage heights are tabulated in order of magnitude, and opposite each is entered for each year of record the total number of days when the flow or gage height does not exceed the given amount. By adding these totals of days for any number of years and averaging, the run-off for an average year is obtained.

It should be noted that, in contrast to most of the methods given above, the average year computed thus contains both the extreme minimum and maximum daily rates of flow, the former being extremely useful in relay power and storage studies.

6. A modification of the second and fifth methods described consists in arranging the rates of discharge in order of magnitude for each year, averaging first the maxima, then the next lower set, and so on down to the minima.

7. When average monthly or weekly flow records are being used, the principles indicated in method No. 5 can still be used, — that is, a table can be prepared showing the number of times various rates of flow have occurred during the period of record. These results, when expressed in percentages, will typify an average year, including the extreme maximum and minimum rates of flow.

Duration Curves of Flows — Average Year.

The results of all of the methods mentioned can and preferably should be shown in the form of duration curves of flow. Ordinarily, the results are plotted with rates of discharge as ordinates and time in months, weeks or days as abscissæ. For facility in making power estimates, it is convenient also to indicate a secondary time scale in per cent. These curves are frequently referred to as "per cent. of time — flow curves," or "duration curves."

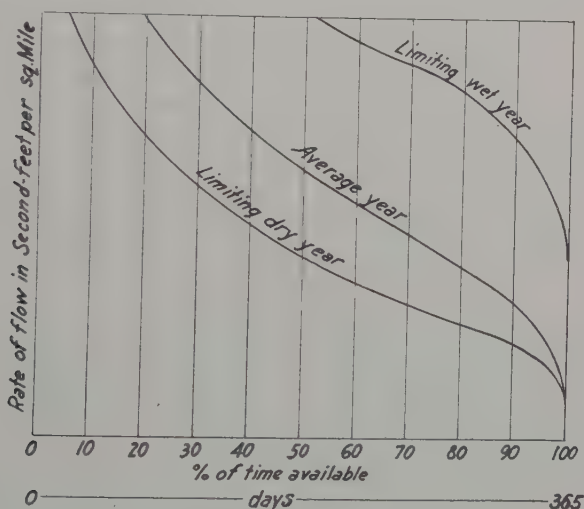


FIG. 1. DURATION OF FLOW CURVES.

Base flow data corrected for storage, when available.

Other Types of Years.

After obtaining the estimated run-off in an average year, averages can be made of such records as fall below this, thereby obtaining what may be called an ordinary dry year.

In some cases, as when estimates are being made of the maximum annual output required from a relay plant under the worst flow conditions that may be expected, a theoretical flow record should be determined for what is known as a "limiting dry year." This is obtained by computing a composite year, consisting of the minimum records for varying lengths of time,

taken from the actual records regardless of the year in which they occurred.

If monthly records are being used, this theoretical dry year is obtained by taking the twelve driest months shown by the records as arranged in accordance with one of the three first methods described. Weekly records can be similarly treated.

In case daily records are being analyzed, this limiting year may be obtained by taking the maximum number of days in any year not exceeding given rates of discharge.

Another method sometimes used in obtaining this limiting dry year run-off is to take from the records, regardless of the actual year in which they occurred, the average flow for the minimum day, week, two weeks, three weeks, two months, etc., and to plot a duration curve of flow from this data.

Using methods similar to the above, a "limiting wet year" can be determined if it is so desired. This type of year is of less usefulness than the dry year, but is occasionally of importance in cases of considerable loss in power from back-water conditions.

Records for actual years which coincide for a major part of the year with the above computed types are sometimes used, in preference to a theoretically computed record. Some computation is necessary, however, to determine the order of magnitude of the record for an actual year.

The "wettest year" has also arbitrarily been defined by one author as that year in which the run-off for the five driest months was the greatest; and correspondingly, the "driest year" as the year in which the flow for the five driest months was the least.*

C-2. — SHORT-TERM RUN-OFF RECORDS AT THE SITE, MODIFIED BY RECORDS ELSEWHERE.

Method of Drainage Area Ratios.

In reducing records at one locality to estimated records at another, the most common assumption is that the unit run-off

* Sargent, E. H., "Long-Term Variations in Stream Flow, Croton and Hudson Rivers," *Engineering News*, Vol. 72, p. 1119 (December 3, 1914).

per square mile at the two points considered is the same, — or, in other words, that the rate of flow in second-feet varies directly as the size of the watershed. This is approximately true for long periods of time when the physical and climatological conditions for each watershed are quite similar. For the short periods this relation rarely, if ever, holds.

This method of reduction is easy of application, and one that is frequently adopted when rough estimates at the site to be utilized are all that is desired. In those cases where there are no records available at the locality in question, it is usually the only practical method.

Hazen Method.

Another method of analysis, practical in the latter case, has been suggested by Mr. Allen Hazen in a paper entitled "Storage to be Provided in Impounding Reservoirs for Municipal Water Supply."* This method is complicated, and frequently requires considerable time for its solution.

Comparison of Integrated Unit Flows.

It frequently happens that there are relatively short-term records available at the site to be developed, while much longer records may exist at another locality in the same or neighboring basins. After the records to be utilized have been compared in a broad way, as indicated in previous sections, and after they have been found reliable, it becomes necessary to ascertain if there is any fixed relation between the site to be developed and the auxiliary stations.

To do this it is usually advisable, first, to plot a diagram of integrated yearly unit flows per square mile at one station as ordinates and the corresponding integrated flows at the second station as abscissæ. By "integrated flows" is meant a mass curve of unit rates, — i. e., the accumulative rates period by period. The same scale should ordinarily be used for both ordinates and abscissæ.

If the yearly integrated flows are found to lie at varying distances from any possible average slope line, it then becomes

* Trans. Am. Soc. C. E., Vol. LXXVII, 1915, p. 1539.

necessary to repeat the operation by months. In other words, the accumulative rates for all of the Januarys are plotted in one diagram, for all the Februarys in another, etc.

It is frequently found that on the monthly basis it is still impossible to draw a graphical slope line which will truly average most of the points. This indicates that the coefficient of relation between stations varies with the seasons rather than by months. Therefore, the next step would be to repeat the above process, this time by first plotting the accumulated January plus February run-offs, then February plus March run-offs, March plus April run-offs, etc. This method can be still further carried to a tri-monthly relation, if necessary.

The above method, either worked out on the basis of single months, successive two-month or three-month periods, or a year, will ultimately indicate some period in which all of the plotted points will lie fairly close to an average slope line. The slope of this line determines the coefficient to be applied to the records for the corresponding period at either of the stations to obtain the other. It is then possible to assume that similar seasonal coefficients apply to the earlier of the long-term records, and thus to extend the short-term records to the same periods as covered by the long.

C-3. — NO RUN-OFF RECORDS AT GIVEN SITE, BUT AVAILABLE ELSEWHERE.

In this case, usually the only available method is that first described in the preceding section as method of "drainage area ratios." In some cases, the results thus obtained can be modified by a judicious use of precipitation data, as indicated in the following section.

C-4. — USE OF PRECIPITATION DATA.

(Especially applicable when no run-off records are available.)

It is possible to estimate approximately the run-off from a given stream if the evaporation (used in its broader sense, including seepage, transpiration of vegetation, etc.) over the entire basin can be determined, by deducting the latter from the aver-

age precipitation. Many attempts have been made to determine a percentage relation between rainfall, evaporation and run-off. Owing to the many factors which influence the amount of evaporation losses, and the uncertainty in their exact determination, together with the many known inaccuracies in the collection of rainfall data, this method of estimating stream flow should be used only as a last resort.

There are three general cases when a study of rainfall records may prove of some benefit.

(1) When no run-off records are available within any reasonable distance.

(2) When run-off records are available at only one or two distant points in the same or similar basins.

(3) When it is uncertain whether the available run-off records cover average, dry or other types of years.

While percentage relations between run-off and rainfall fluctuate through wide limits, it is sometimes necessary as a last resort to assume approximate values for typical years in a restricted locality.

The following rule was presented by Mr. C. E. Grunsky:*

"The percentage of the seasonal (12 months) rainfall which appears in the stream as run-off, when the rain is less than 50 in., is equal to the number of inches of rain. When the seasonal rain is in excess of 50 in., 25 in. thereof goes to the ground (evaporates, etc.), the remainder is the run-off."

That is, if P =percentage, R =rainfall and Q =run-off,

When $R < 50''$, $P=R$ and $Q=PR$.

When $R > 50''$, $Q=R - 25''$.

There are many exceptions to this rule, when used promiscuously, so that it should be used with caution, especially since it was developed for western conditions. No modification has been attempted by the writer as applicable to New England conditions. For example, records of run-off and rainfall of the Housatonic River at Falls Village, Conn., both prove and disprove it (rainfall in this case may not necessarily be the average

* Proc. Am. Soc. C. E., May, 1915, p. 1281.

for the basin above, as there are few rainfall records available in the actual basin):

	Rainfall. Ins.	RATIO OF RUN-OFF TO RAINFALL.	
		Actual. Per Cent.	Grunsky. Per Cent.
1913	49.06	49.3	49.0
1914	32.32*	63.0	32.3

Estimates of Run-off from Rainfall.

In deducing run-off estimates from rainfall records it is first necessary to make a careful examination of all rainfall records in the basin above the site under consideration and determine a fair value for the average, maximum and minimum yearly amounts.

A study of the annual relations between run-off and rainfall † in other not too distant basins will determine the percentage relations for similar types of years which must be assumed as applicable to the given basin. The monthly distribution of run-off in these other distant basins will serve as an index of that most probable in the given basin.

The above method is approximate. In drawing conclusions from rainfall records it must be remembered that before averages of a number of stations can be used, either the period of time used should be the same for all, or an estimate should be made for the longer period covered, using the shorter term records as a basis. Methods for doing this are well known and will not be further treated here.‡

Those who have made any considerable study of the question of the percentage relation of run-off to rainfall will have noticed that it may vary materially in two years having practically the same total precipitation. Besides the question of its distribution, probably the factor principally responsible for this variation is the relative height of the ground water table. To form some idea of the amount added or drawn from this

* Lowest rainfall on record in twenty-six years.

† See "Relation of Rainfall to Run-off," by Geo. W. Rafter, U. S. Geol. Survey, Water Supply Paper No. 80.

Also, "Computing Run-off from Rainfall and Other Physical Data," by Adolph F. Meyer, Proc. Am. Soc. C. E., March, 1915, with subsequent discussions.

‡ See Progress Report, 1908, New York State Water Supply Commission, p. 143.

ground-water storage, it is necessary to collect such data as may be available regarding the general changes in height of the water surface in existing domestic wells, marshes, etc. Usually it is very difficult to find any reliable information of this sort, and the problem is rendered the more uncertain. This suggests the advisability of some government or state department collecting a certain amount of hydrographic data along these lines.

Rainfall as Modifying Distant Run-off Records.

When run-off records are available at one point in a basin, while estimates are desired at a quite distant site, a study of available rainfall data may serve as a basis of modifying the known run-off records to suit the new locality.

Let us assume two sites, A and B, the former being the station further upstream.

The first step consists in obtaining the mean effective elevations of the basin above the upper and lower sites and between them. The total average annual precipitation on each area may be assumed to be proportional to the average elevation of the basin above each site, or —

(mean elevation above A) $\times$ (its drainage area in sq. mi.) = a

(mean elevation A to B) $\times$ (its drainage area in sq. mi.) = b

(mean elevation above B) $\times$ (its drainage area in sq. mi.) = $a + b$.

The above indicates that the total annual precipitation on the area above A is $\frac{a}{a+b} = X\%$ of the total at B.

This is $\frac{X\%}{\text{D.A. at A} \div \text{D.A. at B}} = Y\%$ of the direct ratios of the drainage areas; i.e., the precipitation per unit of area of watershed above A is $Y\%$ of that of the entire basin above B (including that above A).

If it is now assumed that the run-off varies directly with the precipitation, $X\%$ of the run-off at B would be coming from A. In general, however, the ratio of run-off to rainfall increases with the rainfall, and rainfall increases with altitude, so that something more than $X\%$ may be expected to come from above A.

If P_h is the average precipitation at the highest station in the basin and P_l is that at the lowest, then

$$\frac{P_h - P_l}{\text{Elevation of } h - \text{Elevation of } l}$$

which indicates the inches increase (or decrease) per foot of increased elevation; or if the two elevations were divided by 100, the increase per 100 ft., a better unit, is indicated. The above percentage relations can now be modified by this last result, if the precision of the base data warrants this refinement.

Ascertaining Types of Years.

One use made of precipitation data in nearly every investigation is to determine the character both of the individual and groups of years covered by available run-off records, — whether the period considered is an average one, an extremely dry or wet one, or of some intermediate type.

This naturally introduces such questions as the “cycles of rainfall” * and allied problems, which cannot be discussed further at this time.

D. — STUDY OF THE AVAILABLE MARKET.

In so far as the line of investigation covered by these notes is concerned, a study of the available market is necessary to determine —

(1) The most probable daily, monthly and yearly load factors.

(2) The average price expected for the general classes of power.

Any field survey of the market should include many other facts not required for the above purposes. As a guide to the essentials of such a survey, the following outline is submitted:

A complete field survey of the available market should furnish the following information:

1. Information from a canvass of present power users.

* See “Cycles of Rainfall,” by D. M. Wood, Stone & Webster Public Service Journal, September, 1913.

- (1) Name of concern.
- (2) Class of work.
- (3) Kind of power.
- (4) Cost of fuel.
- (5) Age and condition of plant.
- (6) Horse-power, installed and used.
- (7) Hours of operation.
- (8) Daily and yearly load factor.
- (9) Will contract for current (yes or no).
- (10) Determine (a) estimated distribution max. demand factor
(ratio max. station load to connected load).
(b) estimated yearly load factor (based on 8 760
hours per year) at generating station.

2. Classification of above information.

- A. Total horse-power in use
 - (1) Now.
 - (2) Five years ago.
 - (3) Ten years ago.
 - (4) Fifteen years ago.
- B. Total horse-power used for
 - (1) Lighting.
 - (2) Industrial.
 - (3) Traction.
- C. Total industrial power of
 - (1) 10-hour duty.
 - (2) 12-hour duty.
 - (3) 18-hour duty.
 - (4) 20-hour duty.
 - (5) 24-hour duty.
 - (6) Intermittent duty.
- D. Tentative agreements for power service.
 - (1) Concern.
 - (2) Horse-power.
 - (3) Hours of service.
 - (4) Rates, dollars per horse-power per year.
 - (5) Annual value at 100% load.
- E. Probable cost of present power to each consumer.

3. Competition in the proposed field.

- (1) Existing steam or other plants.
- (2) Prevailing cost of steam or other power analyzed.

4. Study of bank clearings, post-office receipts and population census, serving as guides as to rate of growth of the community. Amount of building construction during recent years as shown by building permits.

A study of the results of such a market survey are of course essential in determining the probable percentage utilization of the water power available during the early years in the history

of a new development covering the period of building up the load. This naturally includes also the tentative planning for additional units, including questions of additional energy available, additional steam requirements, etc.

LOAD FACTOR.

As stated above, one of the essential results of the market investigation is a determination of the probable load factors at which the new plant will run.

"Load factor" as used in these notes is the ratio of the average to the maximum power during a certain period of time, as a day, month or year.

In the majority of investigations only the broadest conclusions can be drawn regarding load factor at the time of making power estimates and determining plant capacities. For this reason it is usually a refinement to assume the shape of the load curve, although it is absolutely necessary to assume some percentage as applicable, — as 40 or 50 per cent.

When this is the case, in computing power from stream flow, it is sufficiently accurate to assume full load conditions for a part of the day corresponding to the load factor, and to assume no load during the balance of the day. For instance, a 50 per cent. load factor is equivalent to a full load for twelve hours, a 40 per cent. load factor for 9.6 hours, etc.

In a few special cases there is enough certainty at an early stage of the investigation regarding the character of the power market to warrant assuming the shape of the load curves. This case will be discussed later under "power estimates."

In connection with load factor, it is essential also to determine the diversity factor of the system load. Diversity factor is the ratio of the sum of the maximum power demands of the subdivisions of any system or part of a system to the maximum demand of the whole system or part of the system under consideration, measured at the point of supply. The more non-coincident these peak services are, the greater will be the diversity factor.

E.—MODIFICATION DUE TO STORAGE AND PONDAGE.

DEFINITIONS.

"Pondage" is used in these notes to mean that water storage capacity available daily or weekly to equalize the variations in the power load. On the other hand, "storage" means that capacity which may be available to increase the extremely low flows for several days, weeks, months or even years. Another way of expressing this is to say that storage is the retention of flood-water for use during times of scarcity, while pondage is the retention of the flow of a stream during hours of light load and for use during hours of heavy load.

The terms "pondage" and "storage" are more or less analogous if a period of time longer than a day is taken. If we adhere strictly to our definitions, however, no confusion should arise from the term used.

It can readily be seen from the above that the study of pondage and storage must follow and not precede at least that portion of the market investigation which will definitely settle questions pertaining to the character of the future loads, such as most probable daily, monthly and yearly load factors, etc.

STORAGE STUDIES.

The next step in the general problem of making power estimates is to modify the natural rates of flow determined for typical years by the use of any new storage, the benefits of which are not already included in the flow data. Usually these studies are made on a monthly (sometimes weekly) basis. Numerous methods commonly used in making storage studies are so well known that only brief reference to the most general tabular and graphical methods will be made in these notes.

Tabular Computations.

Some engineers make tabular computations, with columns headed something as follows:

1. Year and month, in calendar order.
2. Natural run-off at the site under investigation, in second-feet or a unit rate.

3. Amount drawn from the given storage reservoir.
4. Amount added to the given storage reservoir.
5. Amount in the given storage reservoir at the end of the month. (In these last three columns the available storage is usually expressed in an equivalent rate for one month.)
6. Regulated run-off at given site. It is necessary to assume a regulated run-off for the apparent longest and worst drought in the period covered by the records and then to find the correct flow by "cut and try" computations.

Mass Curves.

Probably the most commonly used method of analysis is that known as the "mass curve." The method consists in adding up the totals of the monthly run-off from month to month (can be applied to other periods than month) for the whole period under consideration, then plotting the successive steps of accretion of the mass as an irregular line or mass curve.

Any desired rate of draft may then be assumed and its successive sums plotted to the same scale. If the rate is uniform, this draft curve forms a straight inclined line which is made to start coincident with some point or summit on the mass curve, and serves to show by the vertical distance between the two curves at any point of time the volume of storage that would have been required to maintain the given rate of flow up to that time.

Characteristic Flow Curves.

A "characteristic" flow curve shows the relation between the regulated rate of flow at any particular point on a stream and the amount of storage required to maintain that rate of flow, this relation being determined from the "mass curve."

References.

More complete details of the above may be found in the following references:

1. New York State Water Supply Commission Reports, especially Fourth Annual Report (1909), pp. 360-364, covering —

- (1) Mass curve for river regulation problems.
- (2) Mass curve for pondage problems.
- (3) Mass curve for auxiliary power problems.
- (4) Mass curve for flood regulation problems.
- (5) Conversion curves.
- (6) Characteristic curves.

2. Maine State Water Storage Commission Reports, 1910-13.
3. U. S. Geological Survey, Water Supply Papers Nos. 198, 279 and others.
4. Numerous standard text-books.

PONDAGE.

It is next necessary to further modify the natural rates of flow for typical years as modified by new storage available, by the use of pondage.

The amount of pondage required in any given case depends entirely upon the load factor or may limit the size of plant for any predetermined load factor (that is, the ratio of the average to the maximum momentary peak load). Whether it is the daily load factor or the load factor for some longer period of time which determines the amount of pondage required, depends upon the conditions in the investigation in progress.

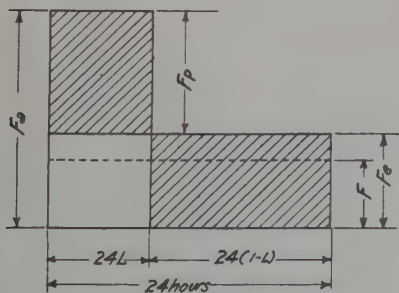


FIG. 2.

1. A conservative method of studying the benefits of pondage is to assume the plant fully loaded for the number of hours determined by multiplying the daily load factor in per cent. by 24, and to assume the plant shut down during the remainder of the day. Reference to Fig. 2 will amplify the following useful relations:

Let F = any average 24-hr. rate of flow, in sec.-ft.

F_e = 24-hr. rate of flow which is completely equalized by pondage, in sec.-ft.

F_a = average of flow available during the working hours, in sec.-ft.

F_p = average rate of flow during the working hours supplied from pondage, in sec.-ft.

C = pond capacity in cu. ft.

P = equivalent average 24-hr. rate of flow in sec.-ft. which the pond would yield with no flow into the pond.

L = load factor, expressed decimally.

$$\text{Then } P = \frac{C}{86\,400}; \quad (1)$$

$$F_e = \frac{P}{1-L}. \quad (2)$$

Case I. When $F < F_e$,

$$F_a = \frac{F}{L}; \quad (3)$$

$$F_p = F \frac{(1-L)}{L}. \quad (4)$$

Case II. When $F = F_e$,

$$F_a = \frac{F}{L} = \frac{F_e}{L}; \quad (5)$$

$$F_p = F \frac{(1-L)}{L} = F_e \frac{(1-L)}{L} = \frac{P}{L}. \quad (6)$$

Case III. When $F > F_e$,

$$F_a = F + F_p = F + F_e \frac{(1-L)}{L}. \quad (7)$$

(F_p = same as in Case II.)

The above equations will indicate greater pondage than is actually required in those cases where there is intermittent drafting and ponding during the period. On the other hand, they are exact for those cases where the draft from pondage is continuous, even if at varying rates, after it once commences, — that is, when the stream flow into the pond is continuously less than the flow from the pond.

2. Mr. Charles T. Main * uses in water-power studies for

* Journal of N. E. Water Works Association, Vol. 21, p. 214.

mill operation what he terms ratios or "multipliers." Water is used, say, for ten hours a day and six days a week. If the pondage is of sufficient capacity to enable storing the entire fourteen hours' night flow and using it during the remaining ten hours, and if no water is wasted, the ratio of the flow used in ten hours to the 24-hr. rate is 2.4, and 2.4 times the 24-hr. rate of flow would be used during the ten working hours. If the entire flow from Saturday night until Monday morning could be stored, the ratio would become 2.8. He usually allows a leakage factor of 10 per cent., reducing the last ratio to 2.52. When the pond cannot hold all of the flow during the time when the plant is not running, the ratio will be less than 2.52.

Formulae and diagrams can be worked out to make these computations less laborious.

With a series of mills, some with small ponds enjoying the benefits of larger ones above, if it takes one hour for the water to get down from the upper to the lower, the multiplier at the lower would be reduced 10%; for 2 hours, 20%, etc.

3. Another method of studying questions of pondage is indicated in the first reference under the previous heading of "Storage — *References.*"

F. — ESTIMATES OF POWER AVAILABLE.

ECONOMICAL PLANT CAPACITY.

There are many methods in use for determining the economical development point in a water-power proposition, some of them of questionable value. A brief mention of a number of these may prove of interest.

1. Referring to the first three methods described in Section C-1, some engineers have assumed that the discharge indicated by the third or fourth wettest month of the computed average year corresponds to the economical development point. Other engineers have used other months down to the sixth driest.

2. Another method seen by the author in special report work consists in selecting the year containing the longest and severest drought and assuming that the discharge in the fourth

or fifth wettest month in that year corresponds to the economical development.

3. In March, 1910, a committee of the New England Water Works Association made the statement * that "a yearly average of approximately one tenth of one horse-power (or 0.075 kw.) per square mile of tributary watershed per foot of fall (which corresponds to a maximum 24-hr. flow or development of water of about 1.4 cu. ft. per second per square mile of watershed, and a maximum available 24-hr. net power of 0.12 horse-power per foot of fall per square mile of watershed) may generally be obtained economically, and a correspondingly greater rate of output if the power be used for less than twenty-four hours per day, and sufficient pondage be available to make such concentrated use of the water possible."

4. The real economical plant capacity appears to the writer to be dependent not only upon the results of the analysis of stream flow base data, but also upon operating load factors and financial considerations, including construction costs and operating revenues.

It is hardly necessary to state that the above methods of estimating capacity have been the result of attempts by various engineers to formulate a rule which would be more or less of an average covering all developed plants known to them.

The proper method would seem to be one of "cut and try," assuming at least three different capacities covering all reasonable operating conditions, computing the available output for each, estimating costs to obtain fixed and operating charges and assuming average prices for the output to enable computing most probable revenues. By plotting these results, it will become evident at what capacity the net revenue and percentage return on the investment is the greatest. In other words, the economical capacity is dependent upon the results obtained by the complete investigation covering all probable operating conditions.

Considering the latitude in selection of methods, depending upon the judgment and experience of the investigator, together with the variations in flow in the estimated type of year accord-

* Journal of New England Water Works Association, Vol. 24, p. 8 (March, 1910).

ing to which method is used in analyzing the base data, it can easily be seen through what a wide range the estimates of economical capacity for the same development by several engineers will vary.

It is desirable to call attention to the fact that, unless special operating conditions exist, resulting from a tie-in with other power plants, the maximum actual peak on a hydro-electric plant will not exceed from 80 per cent. to 90 per cent. of the installed capacity. Allowances should be made for this when computing either the economical capacity or the power available from a given installation.

In that which follows, methods of estimating the power available for any given plant capacity will first be discussed, followed by a few brief remarks regarding the financial considerations referred to above.

ESTIMATES OF POWER AND ENERGY.

Briefly reviewing the steps leading up to the computations of power and energy, it is first necessary to collect and analyze the base data, obtaining an estimate of the run-off at a given site for the type of year most pertinent to the case under consideration. In that which follows, it is assumed that the records have been arranged in the form of a "per cent. of time-flow curve, corrected for storage," although the method to be described can likewise be applied with some minor modifications to any actual hydrograph.

In that which follows, a general method is offered for purposes of discussion, involving a minimum of laborious computations and yet giving a considerable amount of the information always necessary in the consideration of plans for developing or enlarging a water-power plant. Some problems cannot be answered by this method, and these must necessarily be left for a special solution.

The most probable yearly, monthly and daily load factor to be expected should next be decided upon. Ordinarily, the expected yearly load factor should be used as a basis for the computations to be described, but in view of possible departures from the expected, it is better practice to compute for a range

in yearly load factor. In that which follows, 30%, 40% and 50% yearly load factors are assumed for purposes of discussion.

In case of relay power studies, monthly and daily load factors to be expected are of importance as affecting the seasonal distributions of the load between the plants, but in case they are used, some utilization factor should be applied to obtain yearly estimates. This will be mentioned again later.

We are now ready to consider in detail the various steps in the computations of power and energy available with a given development scheme. A few necessary assumptions will be mentioned in their proper places.

General Method of Computing.

1. For ease in tabulating, it is suggested that computations should be based upon per cent. of time, by 5% intervals, commencing with the minimum flow. The first column in the tabulation, then, should perhaps be headed "per cent. of time available," starting at 100% and decreasing by 5% intervals.

2. The 24-hr. rate of flow as corrected for storage and corresponding to each 5% interval should next be tabulated.

3. In the case assumed for discussion, the next three columns should have the general heading "Flow available at given load factor," and a column should be allotted to each case, — 30%, 40% and 50% load factor.

The broad assumption is here made as described under a previous section, "Pondage," that the plant is assumed to be fully loaded during a number of hours corresponding to the load factor and idle during the remaining hours. Formulæ for computing the flow are indicated in the same section on page 99.

It should be noted that in assuming that the daily load factor is the same as the yearly, the question of water utilization during the year has been taken care of to a certain extent.

4. The next problem is to compute the "net head available," and this usually consists of three steps. The net head available is determined by the pond elevations above the dam, the losses through the water passages and the elevations of the tailwater.

In general studies prior to construction, unless actual relations can be determined, it is usually assumed that the tail-

water elevation will stand at the same height for a given rate of flow after construction as it does before.

Usually it is sufficiently accurate to assume the losses through the water passages as a constant throughout the computations.

Granting the last two assumptions, it is possible to draft a curve of relation between head and flow after construction, *exclusive* of draw-down of pond for equalizing daily (or other) load factor.

The final net head available can next be computed as a separate step by subtracting the average loss of head due to draw-down of the pond, whenever the rates of flow are less than that required for the full plant capacity.

For any point on the duration of flow curve (or 5% interval in the table under construction), the amount of water required from the pond during a 24-hr. period for equalizing any given load factor is the difference between the flow available at any load factor and the natural flow. To obtain the maximum draw-down of the pond during this 24-hr. period, the draw-down in feet corresponding to the total pondage available is multiplied by the ratio of the required to the total pondage expressed either as a volume or as a rate of flow, properly modified by load factor.

On the assumption that the draft from the pond is uniform (i.e., neglecting the shape of the daily load curve as previously mentioned) and that the depletion curve for the pond is a straight line, the average draw-down will be one half of the maximum. For ordinary conditions, these two assumptions lead to no material error.

5. Either from the known characteristics and efficiency of the wheel and generator actually to be installed, or from general relations from manufacturers' catalogs, the power corresponding to the flow available at various load factors and net heads can next be computed, in either horse-power or kilowatts, regardless of the limitations due to any specific number of units. In other words, the power actually available in the river as a source is thus computed for the desired range of load factors. Other losses, such as for excitation, should also be included.

6. A new table should next be prepared with "per cent. of time available," "corresponding 24-hr. rates of flow," and "net head available" columns, starting from 0% of time and increasing by 5% increments. In other words, this table commences with the high-water end of the duration curve, and the net head, of course, cannot include any draw-down of pond. From

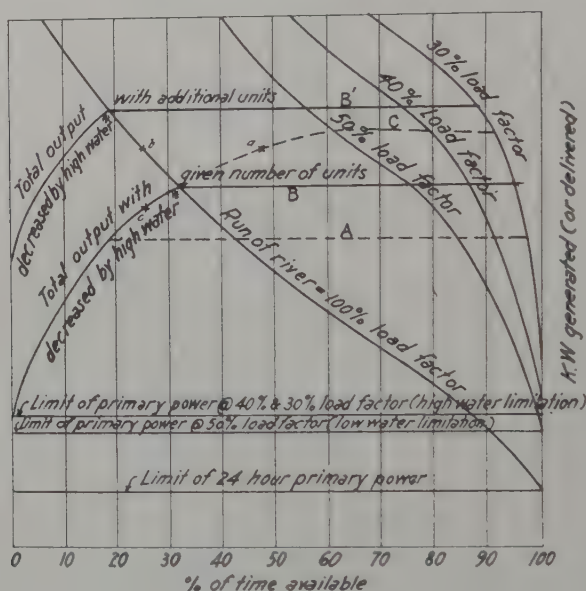


Fig.3

POWER CURVES

* Decrease due to loss in head.

the known characteristics of the wheel and generator, the total available output for any given number of units can be computed.

Diagrams.

Power Curves.—The results of the preceding computations can be plotted in the form of "power curves," with power

plotted as ordinates and per cent. of time available as abscissæ. Fig. 3 has been prepared to illustrate diagrammatically the general case discussed.

The results obtained under item 5 preceding are first plotted, the resulting curves representing the power available at varying load factors (30%, 40%, 50% and 100% here assumed) regardless of any limitations due to a specific number of units.

The results obtained under item 6 preceding are next plotted, indicating the total available capacity or output in kilowatts that could be obtained with a specific number of units. This curve starts at 0% of time (i.e., at the high-water side of the power curves).

At extreme high-water times (0% of time) the net head and consequently the output is at a minimum, due to backwater conditions. As the flow decreases, the head and output increase until a point is reached when all of the 24-hr. rate of flow is consumed by the wheels, i.e., at the intersection of output curve from given number of units with the run-of-river or 100% load factor curve, unless limited to a lesser capacity by the number and size of the units installed. From zero per cent. of time to that per cent. corresponding to this intersection point, the machines can be run at full water capacity for twenty-four hours a day, and the total energy possible to be obtained is only limited by the actual load conditions expected (load factor).

As the flow decreases still further, it is necessary to make up from pondage the deficit required by the wheel capacity. From the previously mentioned intersection with the run-of-river power curve, the total capacity available from a specific number of turbines will follow a horizontal line (or line of constant power "B" in the diagram) until it in turn intersects the "power available in the river at a given load factor" curve. For the per cent. of time covered by this horizontal line the machines can be run at full capacity, but for a number of hours gradually decreasing from twenty-four to that corresponding to the given load factor.

From the latter intersection, the total capacity of all of the wheels can no longer be maintained by pondage, and the total power available from a given number of units will fall back

along the given load factor curve, ending at 100% of the time. For this latter portion of the time, the units can be operated for a given number of hours each day corresponding to the load factor, but with decreasing total power output.

In reality, the line "B" is not horizontal, but slopes slightly downward to the right. As more and more pondage is used, the average net head available decreases somewhat, due to draw-down of pond, with resulting changes in efficiency relations and slight decrease in power available.

The available plant capacity cannot continue to increase beyond the 100% water load factor curve, as to line "C" in the diagram. To show that this is true, consider any point (a) in this line "C." It corresponds in kilowatts to (b) on the 100% run-of-river curve, having practically the same relations between flow, head and power. Obviously the total plant output possible at (b) is indicated by the limiting output curve directly beneath it on the same per cent. of the time line at (c).

In the case of Fig. 3 as drawn, the primary power available at 100% and 50% load factors is determined by low-water limitations. On the other hand, it should be noted that the low-water limitations for a 40% load factor are higher than the high-water limitations, and that for all load factors less than about 45%, the limitation of primary power in the figure as drawn is determined by the power available at times of extreme flood (zero per cent. of time). These relations apply only to the diagram under discussion and do not necessarily apply to other cases.

Summary Tables and Curves.—Much interesting data can be taken from these curves, and presented in other summary tables or curves.

The primary plant (or delivered) load corresponding to any load factor can easily be obtained, and the corresponding yearly energy output in kilowatt (or horse-power) hours estimated ($\text{Kw. Hr.} = \text{Kw.} \times 8760 \times \text{load factor}$).

The secondary power (or delivered) load for varying lengths of time can be obtained as follows: Slide the horizontal per cent. of time scale upward to successive points where the distance between the curve of "total output at high water" and

a given load factor curve will equal 95%, of the time, 90%, 85%, etc., noting the successive differences in load between the successive time intervals. The yearly energy output corresponding to these successive differences can easily be obtained in a manner similar to the primary output, adding the new factor to the previous equation, "times average per cent. of time."

The same results can be obtained by the use of a planimeter, if so desired.

Power curves as shown are extremely useful in studying the effect of successive blocks of power sold at different load factors, and afford an easy means of determining the balance of power left at any given load factor.

The data obtained from such power curves can easily be plotted in a series of useful diagrams. For example, one set might show primary and secondary loads available with varying load factors; another set, the corresponding yearly energy output.

Numerous useful relation curves can be prepared while compiling the power table; for example, relation between net head and switchboard or delivered loads, relation of pond to tailwater level for varying conditions, etc.

Approximate Method.

In general cases it is customary to make approximate power computations as follows:

$$(1) \text{ Hp. (turbine) } = \frac{Q \times h}{11};$$

$$(2) \text{ Hp. (electrical) } = \frac{Q \times h}{12};$$

$$(3) \text{ Kw. } = \frac{Q \times h}{16};$$

when Q = rate of flow available.

h = net head available.

Hp. = horse-power generated at switchboard.

Kw. = kilowatts generated at switchboard.

The reduction factor in equation (1) is based upon an average turbine efficiency of 80%, while that in equation (2) assumes

an average plant efficiency of 73.3%. The reduction factor in equation (3) is obtained by multiplying equation (2) by $\frac{3}{4}$, the approximate relation of kilowatts to horse-power.

The over-all plant efficiency may vary through a wide range during any single day. In one case the writer has seen this vary from 48% to 86%, with an average of 74%, or practically that obtained by equation (2).

To obtain delivered wholesale power at high tension a liberal allowance for all transmission losses, depending upon length of line, size, etc., is from 10 to 15%, so that the above results should still further be reduced. If an 87½% transmission efficiency is assumed as a fair average to be used, the over-all system efficiency would equal 64%.

It is often advisable to install one unit of capacity about equal to the ordinary minimum stream flow. Where larger units are installed, or when the loads are such that they operate through a wide range of gate opening, the question of lost efficiency due to light loads on the unit may become important, and some further allowance should be made in the power estimates.

Utilization Factor.

The term "utilization factor" has been coined to define that coefficient by which the total energy is reduced, to make an allowance for changing efficiencies due to the character of the load, actual daily variations in load factor from that assumed, leakage and waste in operation, percentage of peak to installed capacity, etc. This utilization factor is applied to all rates of flow, modified by the use of the pond, up to that corresponding to the full station capacity. Its amount should be higher if computations are being made on the basis of an assumed yearly load factor than if on the basis of an assumed monthly load factor.

Some engineers allow a factor of safety in the original flow records by deducting, say, 10 per cent. from available stream flow before making the estimates, this to cover losses in operation and leakage. It is a question of individual judgment whether such allowance should be made, especially in view of the fact that some conservatism has already been used in the

ILLUSTRATIVE CASE OF APPROXIMATE METHOD OF COMPUTING POWER AND ENERGY AT A GIVEN PLANT.

Per Cent. of Time Available.	AVERAGE YEAR (1900-1914).			Available Kw. in River at 35% Load Factor.	AVAILABLE Kw. Hr.	
	24-hour Rate of Flow in Sec.-ft. (2)	Sec.-ft. Available at 35% Load Factor. (3)	Differ- ences. Col. (3).		Successive.	Total.
Col. (1).	(2)	(3)	(4)	(5)	(6)	(7)
100	916	2 620		12 430		32 400 000
95	1 250	3 570	950	16 970	11 450 000	43 850 000
90	1 490	4 090	520	19 400	5 950 000	49 800 000
85	1 710	4 310	220	20 500	2 380 000	52 180 000
80	1 870	4 470	160	21 200	1 637 000	53 817 000
75	2 110	4 710	240	22 400	2 303 000	56 120 000
70	2 490	5 090	380	24 150	3 410 000	59 530 000
(66.5%)			(170)	(25 000)	1 510 000	
65	2 740	5 340		25 350		61 040 000
60	2 890	5 490	...	...		

Base data.

Plant capacity = 25 000 kw.

Net available head = 76 ft. (variations in head neglected).

Pondage available = 78 750 000 cu. ft. for 5-ft. draft.

Load factor = 35%.

Explanatory of table (slide rule computations).

Col. (3) — Pond will completely equalize all daily flows at 35% load factor up to 1 400 sec.-ft.

Above 1 400 sec.-ft., $F_a = F + 2\ 600$ sec.-ft.

Col. (4) — Ordinarily omitted, but included here for clearness.

Col. (5) — $Kw. = \frac{F \times 76}{16} = 4.75 F$.

Col. (6) — Kw.Hr. (successive) =

$$\underbrace{\text{Power constant}}_{4.75 \times F} \times \underbrace{\text{Hours per year.}}_{8\ 760} \times \underbrace{\text{Utilization.}}_{35\%}$$

$$4.75 \times F \times 8\ 760 \times 35\% \times 85\% \times (\text{av. per cent. of time available}).$$

Load factor.

arrangement of the base data. It seems the better practice to include this in the utilization factor, as noted in the previous paragraph.

Refinement of Computations.

The question may well be asked as to what degree of precision is warranted in the computations. The writer has always believed that usually it is good practice to carry out the computations of power and energy to as much refinement as can be obtained from a slide rule, then rounding up the final estimates to good even figures to eliminate "bargain house prices," as one engineer has so aptly called those power estimates carried out to four, five or even more significant figures. In other words, it seems preferable to carry out the assumptions and computations to greater refinement than is warranted in the final answer, to prevent "creeping errors" from showing up in the estimates finally presented. As stated before, estimates for the future are being based upon past records, and in many cases only the broadest prediction can be made regarding such features as load factor, etc. After once making a good guess as to these factors, it would seem desirable to stick as closely as possible to it in the detail estimates. Much the same method is always followed in cost estimating.

CHARACTERISTIC LOAD CURVES.

In the foregoing, only broad assumptions were made as to the effect of load factor on the power available from the stream. In some cases, more refinement is desirable.

An ingenious method of studying the typical load curve and the resulting limits of plant capacity that may be expected was presented before the American Institute of Electrical Engineers by Mr. Cary T. Hutchinson.*

He first deduces a duration curve of flow by days as previously described, and from that obtains a "per cent. deficiency curve" where per cent. deficiencies are plotted as ordinates

* "The Economical Capacity of a Combined Hydro-electric and Steam Power Plant," by Cary T. Hutchinson, American Institute Electrical Engineers, March, 1914.

and flows in second-feet or second-feet per square mile are plotted as abscissæ. He next suggests a study of actual load curves, developing what he calls a "characteristic load curve."

The first step consists in deriving a representative daily load curve, departing from the usual procedure by plotting per

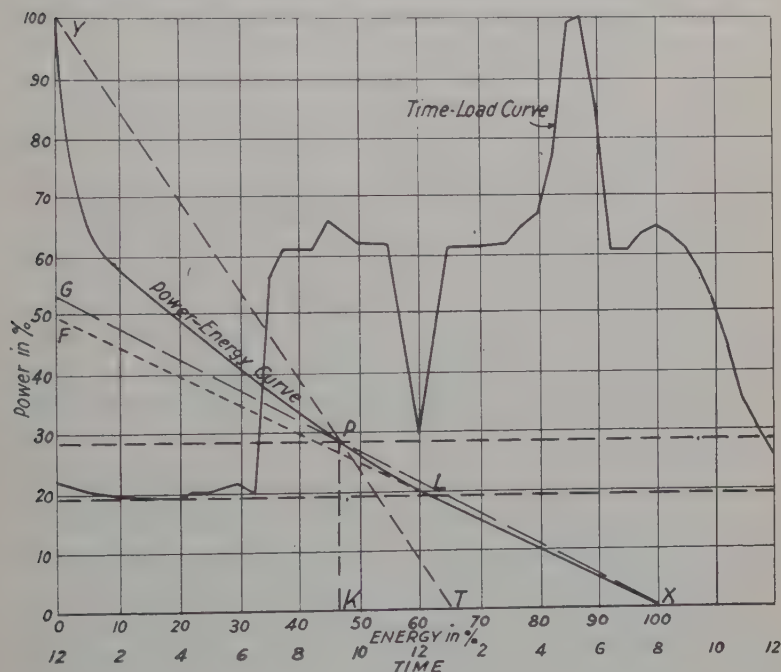


Fig.4

CHARACTERISTIC LOAD CURVES

cent. of power against time. (See accompanying Fig. 4, representing a combined light, traction and power load.) This is done to reduce loads covering a wide range in peak to some common basis of comparison, just as the hydraulic curves are often plotted in second-feet per square mile.

From this load curve he derives a power-energy curve, or,

as he calls it, a "per cent.-load" curve. The ordinates are per cent. of power and the abscissæ per cent. of "peak-energy," using the same length of scale for both. This curve is obtained by drawing successive horizontal lines and determining the per cent. of the load lying above it. For example, the abscissa OK of the point P gives the percentage of the total energy lying above the horizontal line through P , or "peak-energy," while the ordinate KP is a measure of the "base load."

This curve consists of a straight line from X up to the point L on the horizontal line through the minimum power and a curve tangent to it. From this power-energy curve, several interesting properties are found:

1. If the straight line XL is extended to intercept the Y axis at the point F , then OF indicates the load factor corresponding to the curve.
2. A straight line from Y through any point P will intercept the X axis at T , and the load factor of the peak load above P is equal to total load factor OF multiplied by OT .
3. A line drawn from X through the point P intersects the Y axis at the point G , and the load factor of the base load is OF divided by OG .

The above enables one to determine at once the capacity of the steam plant required to meet any assumed conditions of the hydraulic development, or, for that matter, any ratio of minimum to rated stream flow.

The following may serve as an interesting guide to the possible combinations of cases likely to arise, although lack of space prevents a detail discussion in these notes:

- A. Peak less than water plant capacity.
- B. Peak equal to water plant capacity.
- C. Peak greater than water plant capacity.
 1. Minimum water day.
 2. Medium stage, flow less than full plant capacity.
 3. Flood stages, unlimited water.
 - (1) Ample pondage.
 - (2) Restricted pondage.
 - (3) No pondage.
 - (4) Effect of storage.
 - (5) Interference by power users above.

Cases A and C are usual, while B is theoretical and rarely found in practice. With ample pondage, the hydraulic plant should carry the peak until the flow increases sufficiently to enable it to carry, in cases A and B, the entire load, or, in case C, the base load.

With no or restricted pondage, the hydraulic plant should, of course, be operated as a base load plant, carrying as much of the load as possible up to its full capacity.

AUXILIARY POWER STUDIES.

It will be evident from what has preceded that the duration curve method of arranging stream flow data with resultant power curves offers excellent opportunity for making studies of relay or auxiliary power problems. If the power for an average year is determined as previously described, the extreme minimum power is also indicated, so that either the required relay capacity to make up a given deficit can be determined at a glance, or the benefits of a definite amount of relay capacity ascertained. (See Fig. 3.) The output in an average year is figured by integrating the area between the line representing total combined water and relay capacity and the flow-power curves at any given load factor.

One problem of particular importance regarding relay power which cannot be obtained from the methods given in the foregoing is the actual calendar time during a given year when the relay power might be needed according to past records. Another is the variations in load factor on the water and auxiliary plants.

If the shape of the load curve is assumed, the most economical division of power between and corresponding load factors of the relay and water-power plants can be determined either by "cut-and-try" methods or as indicated under "characteristic load curves."

In many power studies it is approximately correct to assume that the system load factor applies to the individual plants, thus simplifying the computations. It is obvious that steam plant capacities under this assumption will be higher (and hence on

the safe side) with a normal load curve than if it is assumed that the hydraulic plant carries the peak load and the relay plant the base during low-water periods, and the reverse during high water.

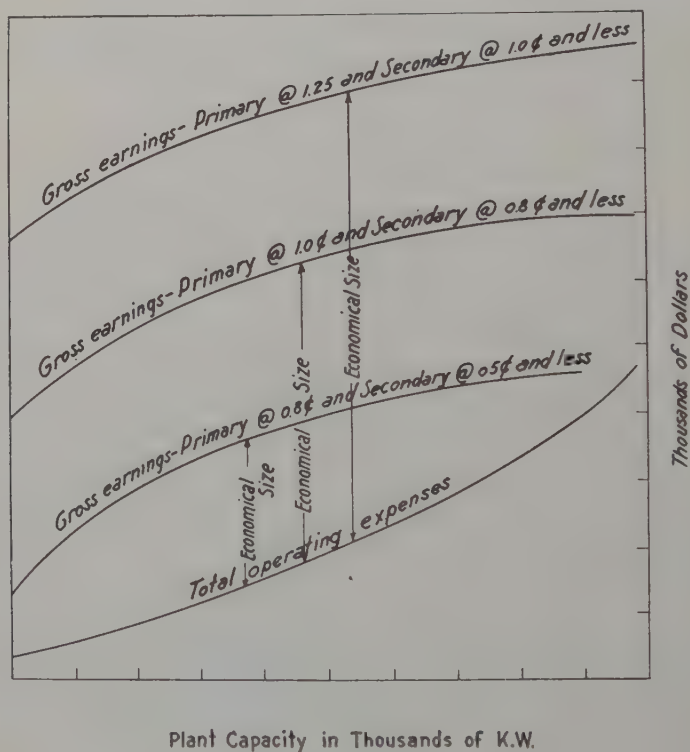


Fig. 5
NET RETURNS, NO RELAY POWER

G. — FINANCIAL CONSIDERATIONS.

The economical plant capacity for both water and auxiliary plants is not only dependent upon the stream flow and resultant power available, considered in connection with the size and character of the market, but also upon the gross and net income

which may be expected from the sale of the commodity power. Accompanying Figs. 5 and 6 indicate two methods of obtaining the most economical water plant capacity, from a study of the power available, with resulting gross receipts, and a determination of the probable operating expenses. That capacity is the most economical at which the net percentage return on the investment is the greatest.

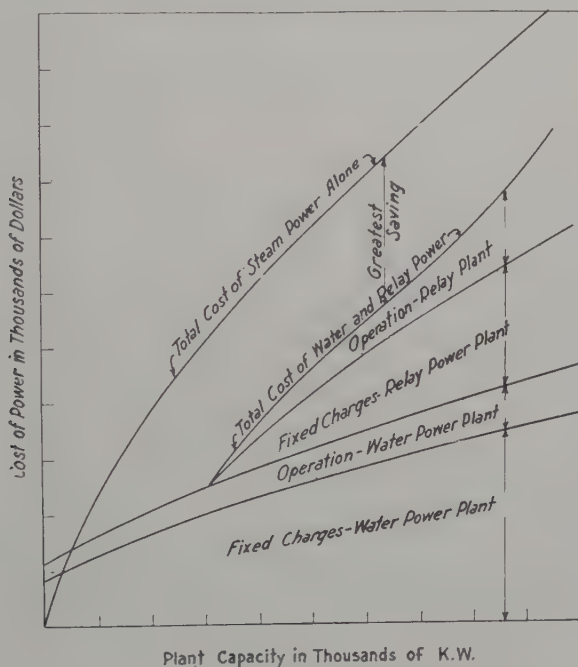


Fig. 6
NET RETURNS WITH RELAY POWER

Further discussion of this subject seems unnecessary, although there are several other interesting methods, all with the same object in view as the above.

CONCLUSION.

The purpose of these notes has been twofold: (1) to show the need of a careful analysis of stream flow records for power

estimates, and (2) to indicate several methods of conducting office investigations. Considerable information condensed into the foregoing will be found scattered through many publications, some of which are referred to. It is hoped that these notes will prove a time-saver for both those who desire a broad outline of the problems involved and those who desire references to the more important publications covering the subject.

Many important references have necessarily been omitted, but the following have been found useful in compiling the foregoing, in addition to those given throughout the text, and contain suggestions for further enlargement of the subject.

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CLEANING OUT LOCK GATE TRACKWAYS AT THE
CHARLES RIVER DAM.

BY EDWARD C. SHERMAN,* MEMBER BOSTON SOCIETY OF CIVIL ENGINEERS.

DURING the construction of the shut-off dam, by which the tidal flow in the Charles River was stopped so that an earth dam could be built, the rolling-caisson gates of the lock were left open in order to afford additional waterway, as the velocity of the current made the work in the river exceedingly difficult. When the shut-off dam was completed and it was desired to close the gates of the lock, it was found that the trackways, or recesses in the floor, were filled with sand, deposited there by the water, so that the gates could not be moved. The deposit in the upper trackway was partly removed by jetting, as the velocity of the current made it very difficult for a diver to work.

The apparatus for jetting consisted of a 2½-in. wrought-iron pipe, with a header at the bottom end. In the header were set six or eight nozzles of smaller pipe, flattened at the end to give long, narrow openings, and aimed downwards about 30 degrees from the horizontal. This apparatus was hung over the front end of the upper lock gate so as to bring the nozzles a little below the tops of the rails on which the gate runs. Connection was then made with the fire pump of a towboat, and water was forced out of the nozzles at a high velocity. Coincidentally, the lock gate was moved forward a few inches at a time.

Progress was slow and finally ceased when about two thirds

*Of Rourke & Sherman, Consulting Engineers, Boston.

of the distance across the lock had been traversed, as stones and other débris which had been buried in the sand accumulated ahead of the gate, the jets being able only to move them forward and not to raise them high enough so that they would be swept away by the river current. It was then necessary to resort to a



LOCK GATE TRACKWAY AT CHARLES RIVER DAM WHICH WAS FILLED WITH SAND TO LEVEL OF LOCK FLOOR.

diver, who completed the work, taking out the remaining material a bucketful at a time. The diver was assisted by a man who worked in the air chamber which surrounds the gate truck, and which is reached by means of an air lock in the gate. As soon as the upper gate was closed there was slack water in the lock, and the work of cleaning out the lower gate trackway was an easy matter for the diver.

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A "MONKEY CART."

By E. F. ROCKWOOD,* MEMBER BOSTON SOCIETY OF CIVIL ENGINEERS.

IN the spring of 1913, the New England Concrete Construction Company was building a weave shed of mill construction



approximately 120 ft. by 420 ft. The first floor of this weave shed was of hard pine plank carried by steel beams and girders

* Chief Engineer, New England Concrete Construction Company, Boston.

which rested on brick piers. There were eighty bays, each 24 ft. by 26 ft. The girders were two 18-in., 55-lb. I's, 24 ft. long, and the beams were 15-in., 42-lb. I's of 26-ft. span and 8 ft. center to center. The tops of the beams came about 8 ft. 0 ins. above the ground, which had been filled with cinders to an approximately level grade. There were about 240 tons of steel in the floor. This was bought direct from the mill.

Bids were obtained from several steel erectors for the erection of this material, but the contractors thought the bids excessive and decided to do the work themselves. They took two pairs of wheels and connected them into a cart with a framework platform. On the rear wheels having a 12-ft. axle was mounted an "A" frame which could be tipped down when necessary to go under work already erected. On the front was mounted a hand winch. The cart was fitted with shafts, but it was found cheaper to use laborers, rather than horses to move the cart. The accompanying illustration shows the cart, which the superintendent of the mill dubbed "the monkey cart." The contractors made a substantial saving over the bids given them for erecting the steel.

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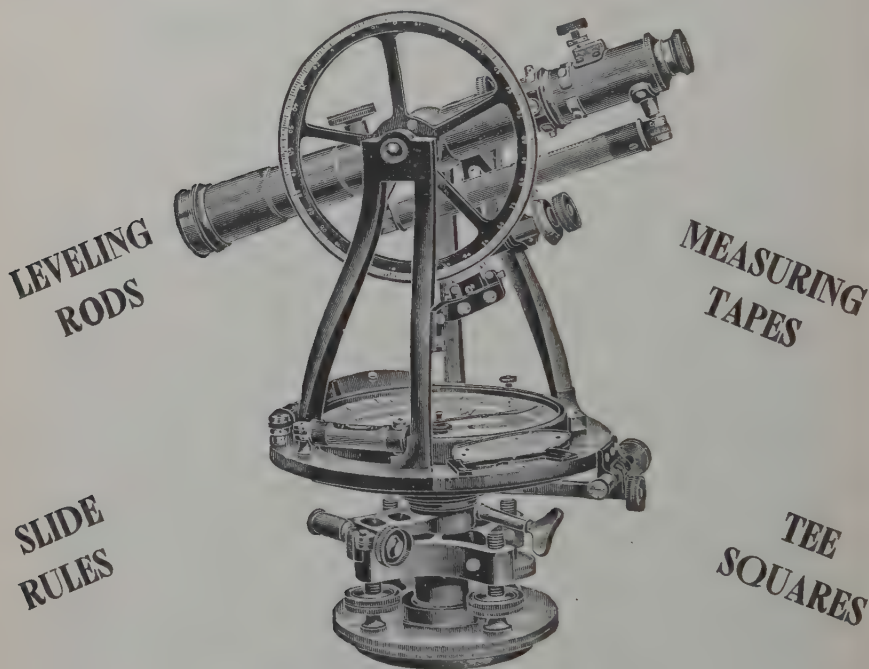
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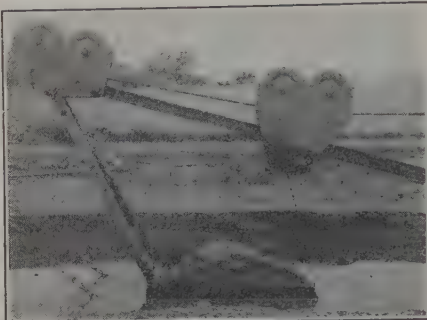
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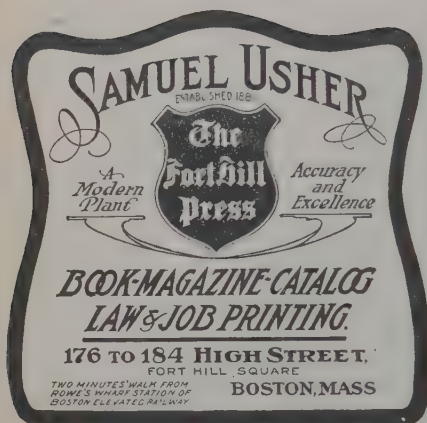
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